

(NASA-CR-161300) DESIGN FABRICATION AND
INSTALLATION OF A YAW MEASURING DEVICE

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DESIGN, FABRICATION AND INSTALLATION
OF A YAW MEASURING DEVICE

FINAL REPORT
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SUMMARY

A yaw measurement device was developed for use with the automated longwall guidance and control system. The new device was packaged to form an integral part of the longwall mining machine. It also contains a number of circuit improvements that make its use superior to that of the original design.

FORWARD

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1.0 WORK PERFORMANCE REVIEW

1.1 General

The original yaw measuring equipment was modified to improve its performance in a number of areas.

These included:

- a) Integrating the yaw measurement transducers into the mining machine understructure.
- b) Utilizing one location along the conveyor track as a systems reference point.
- c) At the request of NASA, a distance measuring circuit was designed and integrated into the yaw measurement equipment. This circuit measures distance from the systems reference point and is for use by NASA to control motions of the mining machine.

The above modifications were made and tested under simulated mining conditions at the Bruceton test facility near Pittsburgh. Results indicate that the yaw measuring equipment after some minor adjustments performed very well.



Figure 1.1 Testing Facility

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1.2 Yaw Transducer

It was the purpose to demonstrate the yaw measuring concept by locating the transducer at a rather accessible location and which is representative of the yaw motion of the coal mining machine. The location chosen was cantilevered from one end of the mining machine. The transducer system was verified as documented in the previous report. During reversal of the direction of the minine machine a rather larger yaw motion was occurring. This motion was not affecting the yaw measurement except when the machine was maneuvered through curves when the kinematic freedom of the suspension system reached its design limitations.

In moving through a 5 degree curve, lateral motions of 1 to 2 inches at the machine became enlarged to 5 and 6 inch displacements at the point where the yaw transducers contacted the spill plate surface. Depending on the location within a curve, one of two things would happen in situations such as these. Either the transducer surface contactor would bottom out within its housing or else it would lose contact with the spill

plate surface. In both instances the measured data was no longer valid.

To remedy this problem the yaw transducers was placed inside the machine, which eliminated the cantilevered support structure. This not only made the large displacement problem manageable, it also permitted the mining machine to be used as a shield to protect the transducers from falling coal.

As part of this redesign effort, the mining machine manufacturer was contacted on the feasibility of making such a modification. Plans and drawings of the contemplated changes were submitted to them for their evaluation. Upon receipt of permission by the Bureau of Mines, the machine underframe was machined to adapt the transducer assembly.

In making the yaw transducer an integral part of the mining machine, the redesign permitted the package to be reduced in size. This was possible for a number of reasons. One of these was that a heavy protective cover was no longer needed to shield the transducers

from falling coal. This function could be performed by the machines superstructure. Another reason for a reduced size was that smaller lateral displacements of the yaw transducers could be translated directly into a requirement for a smaller housing displacement. Finally, the cantilevered support structure could be eliminated by using the mining machine underframe as the new support base.

1.3 System Reference Point

Replacement of multiple reference points by a single reference point was another objective if this modification. This was achieved by adding a cycle counter to the discriminator circuitry.

The cycle counter functions as a length measuring device that is reset to zero for each five feet of forward motion. By forcing the reset action to occur at the point where a bias angle measurement is to be made, the need for multiple reference points is eliminated. Furthermore by making the first reference point identical to the first bias initiation point, the counter can be initialized and reset with a minimum of circuitry.

The cycle counter was designed so that it remained reset until the mining machine passed the system reference point. Upon actuation the first bias angle measurement was made as the mining machine moved forward. Thereafter track angle measurements were made in the same manner as the original design. At the second and succeeding bias locations, however, initiation of the bias measurement was achieved by the cycle counter being reset to zero instead of by additional actuations of the discriminator switch. Again the remaining measurement functions and circuitry were identical to those of the original design.

1.4 Analog Distance Measurement

An analog distance circuit was developed for use by NASA to control the longwall machine. This circuit consists of a binary counter and a D/A converter. The counter accepts 53.5 pulses from the optical encoder for each linear foot of forward motion. The accumulated digital data is changed into an analog signal by a 12 bit D/A converter and provides a signal which varies from -10 to +10 volts. This is equivalent to 120 feet of linear motion.

The analog distance circuit operates in conjunction with the system reference point from which all measurements are made. When the mining machine passes the reference point the discriminator resets the distance counter to zero. The D/A converter then develops an output voltage of -10 volts. After traveling 120 feet, the counter accumulates a value of 6396 which is translated into a +10 volt signal by the D/A converter.

2.0 CONCLUSIONS

The prototype yaw measurement equipment was repackaged to integrate the transducer assembly with the coal mining machine. The prototype model used a cantilevered structure to house the yaw angle transducers. The new design has relocated the yaw angle transducers to make it an integral part of the longwall mining machine. Tests at the Bruceton facility confirm that the new design provides better performance and improved accuracy over the prototype.

Improvements in the electrical circuitry permit the system to operate with one reference point rather than with multiple points as was done with the original equipment. In addition an analog distance measurement circuit was added to permit better control on the mining machine by the central computer/control device.

3.0 RECOMMENDATIONS

The concept of the yaw measuring devices as far as feasibility and accuracy has been demonstrated. The device is the basis for a coal face measurement system, which ultimately may lead to the automated longwall miner. The next steps in this pursuit is to obtain information on reliability of the basic measurement system under mining conditions. It is recommended that hardware including the transducer assemblies, the process electronic, and data processor with operator controls is redesigned, packaged and built to mining standards and regulations.

Coordination with a mining machine manufacturer would assure the interface capability for testing of the coal faces measurement system on a longwall miner in an actual production environment.

when the trailing transducer has moved an additional foot to 4.25 feet and the leading transducer to the 1.75 feet point. Figure 1.4 illustrates the technique used to make these measurements.

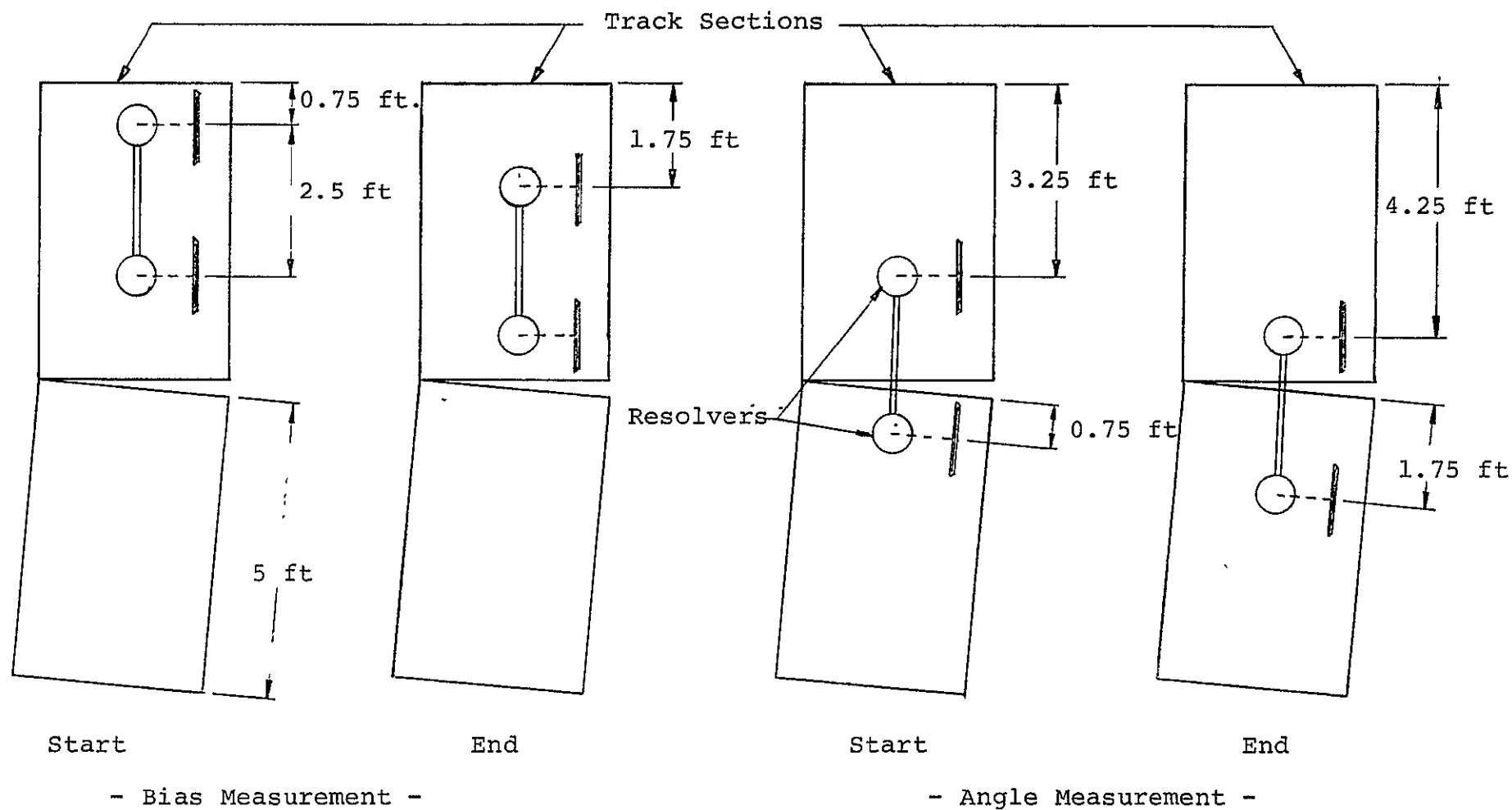


Figure 1.4: Bias and Track Angle Measurement Technique

1.5 Yaw Measurement Surface

Prior to designing the yaw measurement equipment, an investigation was performed to determine an acceptable surface over which angle measurements could be made. An acceptable surface was defined as one with the following characteristics:

- a) A vertical surface parallel to vehicle motion.
- b) A surface that is reasonably flat.
- c) A surface that is rigid enough to retain its flatness over a long period of time.

Surfaces that met this criteria were:

- a) Face side rail

The face side rail is a solid rail made from non-machined barstock. The surface is narrow and located at ground level. It is covered with coal during normal mining operations.

- b) Gearrack face

The gearrack face is located on the gob side away from the coal face at a location

approximately two feet above the ground. It contains a section that is solid but narrow. The available surface is further limited by rail connecting plates. This surface is subject to deformation in the form of burrs that occur because of gear hobing and machine movement.

c) Gob side support structure (spill plate)

The spill plate on the gob side support structure is located beneath the gearrack approximately six inches above ground. It has a surface that is narrow but free from obstructions. It is capable of taking horizontal reaction torques without distorting.

A limitation is that the surface is only accessible at the ends of the mining machine.

The three candidate surfaces are illustrated in Figure 1.5. Of these, the spill plate surface was considered most desirable for the following reasons:

- a) The surface is reasonably flat.
- b) The surface is rigid enough to retain flatness over an extended period of time.
- c) The surface is free from falling material.
- d) Small vertical movements of the mining machine do not remove the measuring transducer from the reference surface resulting in erroneous measurements.
- e) The surface allows attachment of a measurement transducer to the machine. The transducer can be mounted so that it is accessible for maintenance without impeding the mining process.

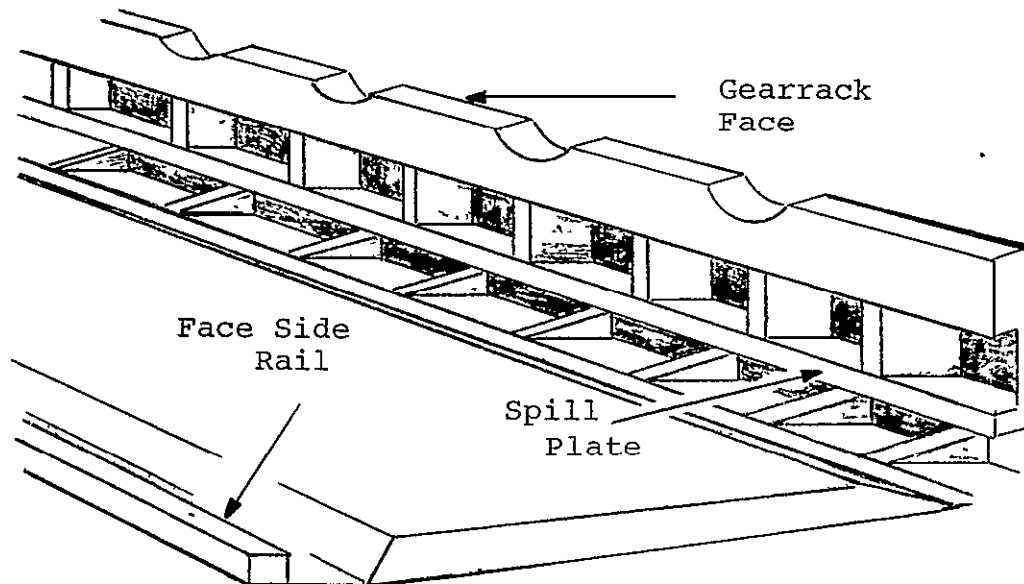


Figure 1.5 Candidate Yaw Measurement Surfaces

1.6 Yaw Measurement Support Structure

The yaw measurement support structure is illustrated in Figure 1.6. It is composed of two parts.

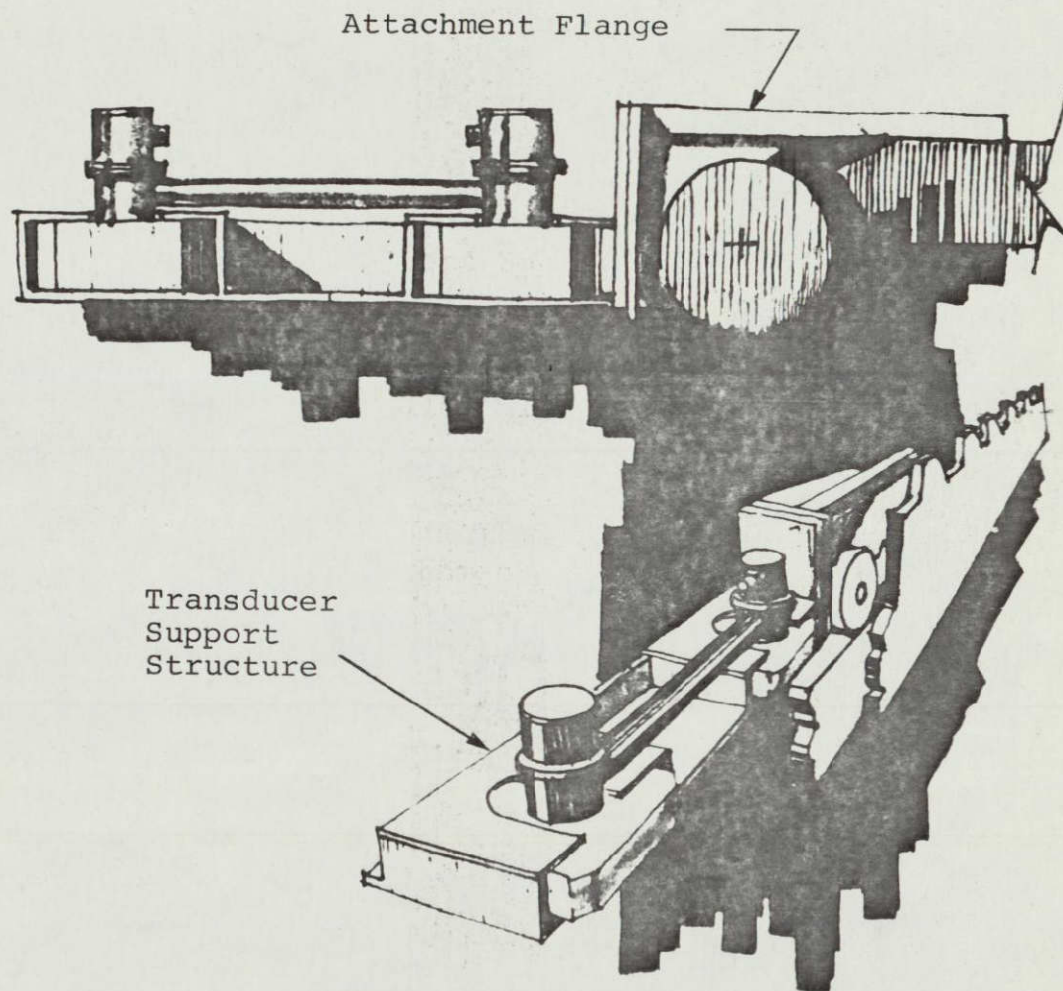


Figure 1.6 Yaw Measurement Support Structure

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The first - a 2" x 2" hollow tubular structure - is welded to the machine undercarriage. This tubing terminates in an attachment flange that acts as a mounting base for the second member - the transducer support structure. This interface was created to permit shimming at the installation site. It allows for a nominal accuracy requirement between the mounting surface of the machine and the hollow tubing.

The transducer support structure is an L-shaped weldment with reinforcing ribs. Guide shoes are provided for each transducer to rest on the rail. They are spring loaded to force the shoes against the reference surface. This reduces the loading and vibration which would be expected from a purely cantilevered design. The shoes have pivot axes for connection to a rod that joins the measuring transducers together. The transducers are housed within a protective structure that is attached firmly to the connecting rod. Protective covers are mounted on the top of each housing to allow access for mounting, wiring and maintenance. (See Figure 1.6.1, 1.6.2 and 1.6.3).

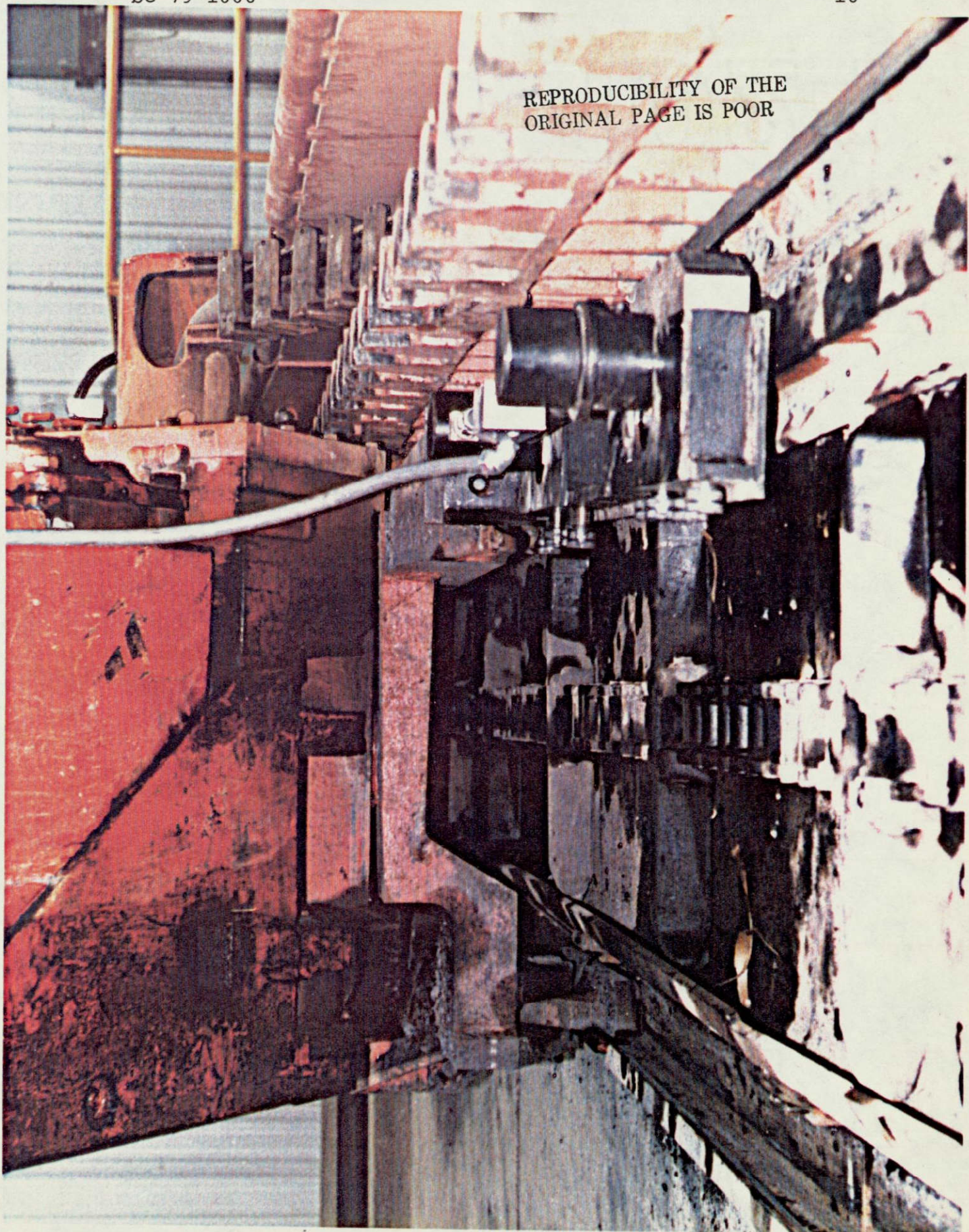
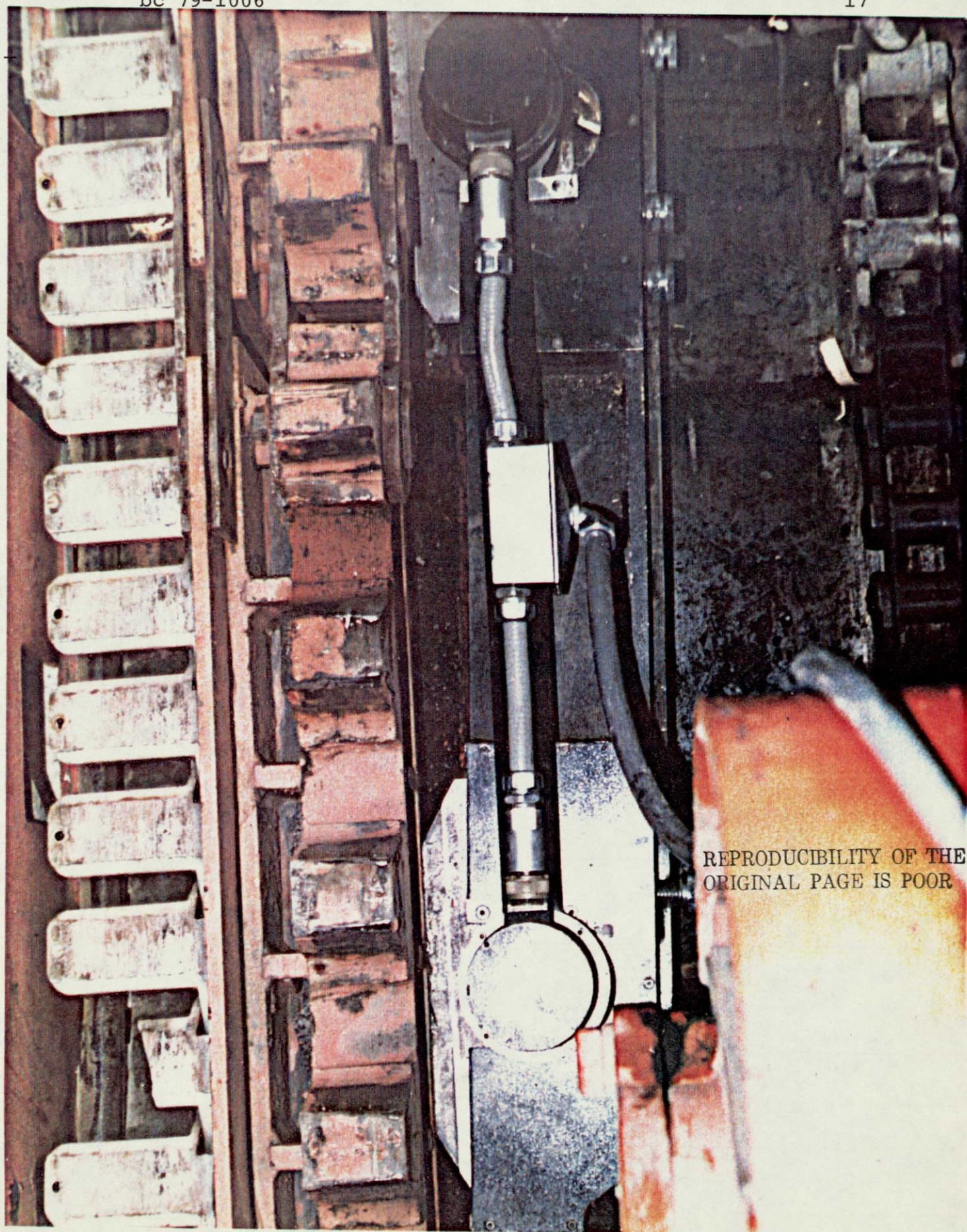
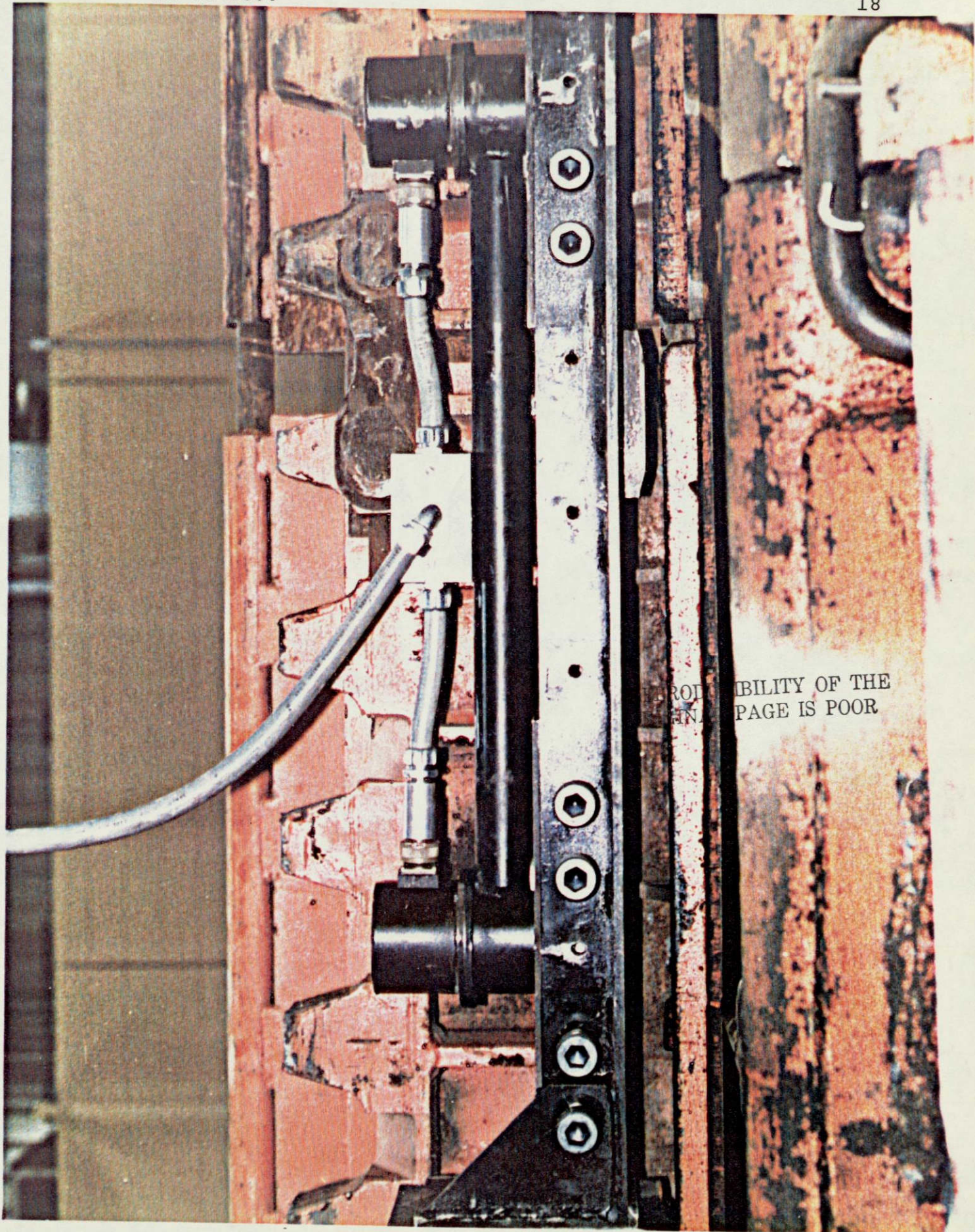


Figure 1.6.1 Angle Transducer Support Structure



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Figure 1.6.2 Angle Transducer Support Structure
Top View



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Figure 1.6.3 Angle Transducer Support Structure
Side View

1.7 Angle Transducer

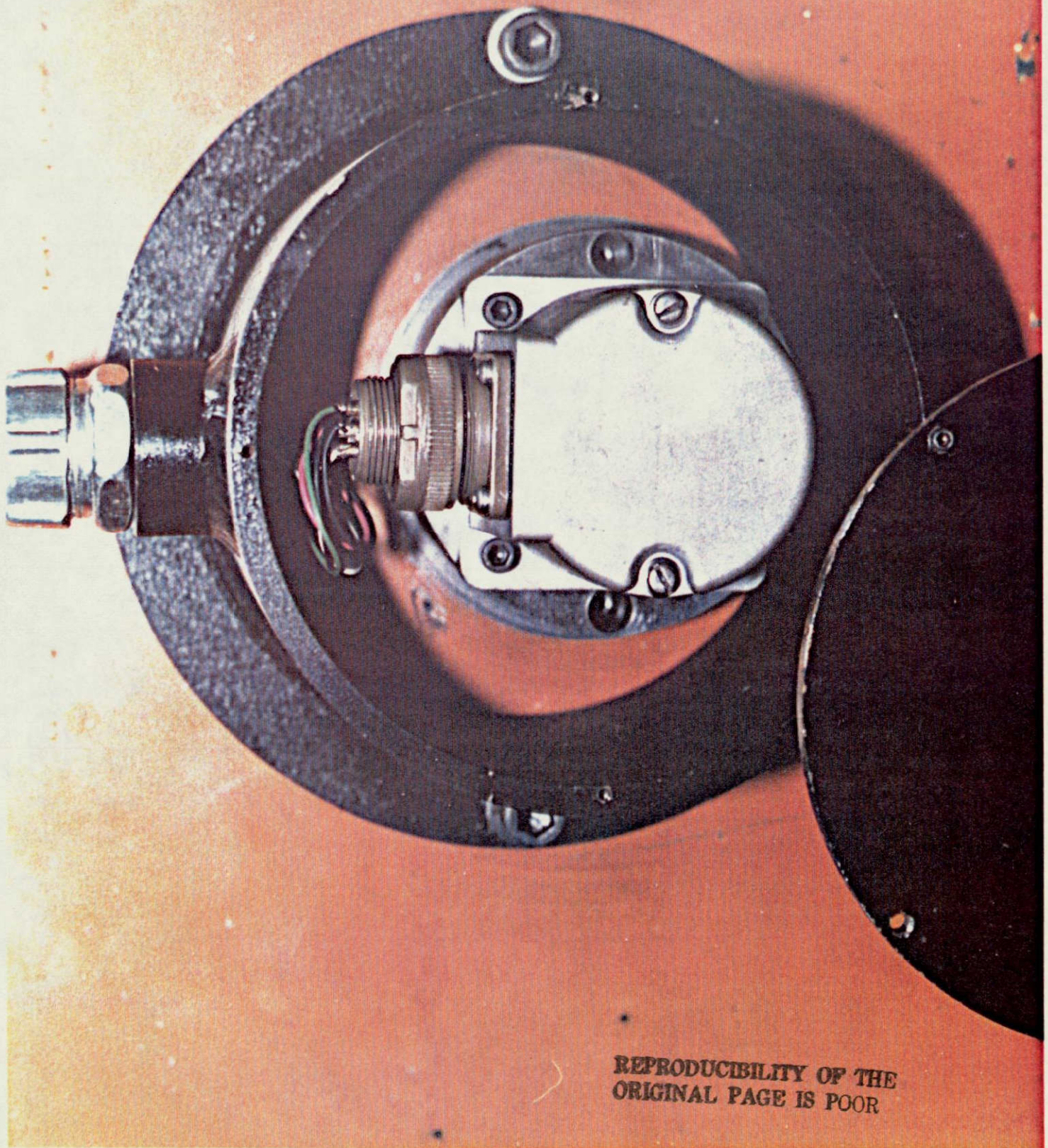
The angle transducer is an electro-mechanical device consisting of two resolvers and electronic measuring circuitry. The resolvers are GFE Bendix 8:1 resolvers having an accuracy of 20 arcseconds. These resolvers are keyed with a 400 Hertz sine wave that is derived from a 1.152 MHz master oscillator. This combination permits an angle to be resolved to 0.015625 degrees of mechanical motion.

The measurement of an angle is achieved by measuring the relative phase between the outputs of the two resolvers. This is illustrated in Figure 1.7. The primary of both resolvers is excited with a 400 Hertz signal. The sine and cosine outputs from each resolver are passed through phase multiplying circuitry which renders phase information for each resolver that is relative to the position of each. These phase signals are compared in an up/down counter that gates the signal from the master oscillator on and off over a 2.5 milli second measurement period. At the end of each

period, the accumulated count value - representing a measure of the angular difference between the two resolvers with the least significant bit being equal to 0.015625 degrees - is transferred to the output buffer along with a data ready signal. The data ready signal informs the wayside receiver that information is available for transfer.

1.8 Distance Measurement Transducer

The distance measurement transducer is an incremental optical encoder of heavy duty industrial construction. It is attached to the mining machine star wheel drive pinion gear through a 1:1 coupler. The encoder generates 200 pulses per revolution which translates into 53 pulses for each linear foot of movement considering each track section as being 5 foot long and having 8 gearrack teeth; and the mining machine drive mechanism as a star wheel with 6 teeth. The encoder is located inside a heavy duty housing designed to safeguard it from damage by the power cable support structure located nearby. This housing is equipped with a protective cover that is removable to allow access to the encoder. (See Figure 1.8).



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Figure 1.8 Distance Measurement Transducer

1.9 Discriminator

The bias and track angle measurements are initiated by the discriminator. The discriminator consists of two parts - an electro-mechanical switch and distance measuring electronic circuitry.

The switch is attached to the mining machine on its gob side. As the machine moves along the track, the switch actuates at each track section. (See Figure 1.9). This initiates the bias angle measurement cycle. This permits the distance measuring circuitry to accept pulses from the linear encoder. Each pulse gates one bias measurement value into a master accumulator until 53 measurements are accepted. The summed value, which corresponds to bias measurements for 1 foot of trackage, is transmitted to the HP 9825 controller for further processing.

The distance measuring circuitry remains active to measure forward distance traveled by the mining machine. It determines when an additional forward movement of 1.5 feet has occurred, rezeroes the



Figure 1.9 Position Transducers

master accumulator and reactivates the circuitry to accept 53 new track angle measurements.

At the completion of the measurement the accumulated sum, which corresponds to angle measurements for 1 foot of track, is readied for transmission to the HP 9825 controller.

The alternating action of making bias measurement and angle measurement on each track section is continued until the total track is measured. Each bias measurement is initiated by a switch movement and each track angle measurement by the distance measuring circuitry. A unique feature of the distance circuitry is its ability to remember location. This quasi-absolute feature prevents measurements from being made at the wrong point should the mining machine reverse direction. A reversal of the mining machine is noted at the immediate instance of its occurrence. The direction and distance it travels are retained in a memory unit until the machine returns to the original point of reversal. Thereon the measurement cycle is resumed until 53 measurements have been accumulated.

1.10 Data Transmission

A serial data transmission network was developed to transfer information from the longwall shearer to the wayside storage mediums. The mechanism for transfer consists of a serial shift register on board the longwall shear controlled by the HP 9825 controller. When data is available at the shearer, a bit value of 1 is set on the transmission line. The HP 9825 recognizes this fact and shifts data out. Data is then shifted out until 18 bits have been read. The outgoing data bit is returned to the zero state and the system made quiescent until the next transmission cycle is to begin.

The data format for one transmission is illustrated in Figure 1.10.1. The read - or data ready bit - is shown in the LSB location. Fourteen angle data bits are presented next followed by the sign bit. The angle/bias data bit has a value of 0 for bias information and 1 for angle information. The MSB bit is a check for odd parity.

1 Bit	1 Bit	1 Bit	14 Bit	1 Bit
Parity	Angle/ Bias	Sign	Angle Value	Read

Figure 1.10.1 Angle Data Format

Since there is a possibility that the HP 9825 controller might fail to accept valid data when it is presented, the transmitter is programmed to recognize this and to send a special code at the next transmission. Such an occurrence arises when a track angle measurement begins before the previous bias angle transmission has been completed - or vice versa. The fault condition is recognized and a transmission of all 1's ensues. The transmission of 1's goes on until it is cleared manually. This feature was added to guarantee that the HP 9825 controller could recognize a fault condition without the need for software programming. During testing this code was detected by the computer. It indicates that this hardware safeguard is desirable.

The complete electronics package for the yaw measurement equipment is illustrated in Figure 1.10.2.

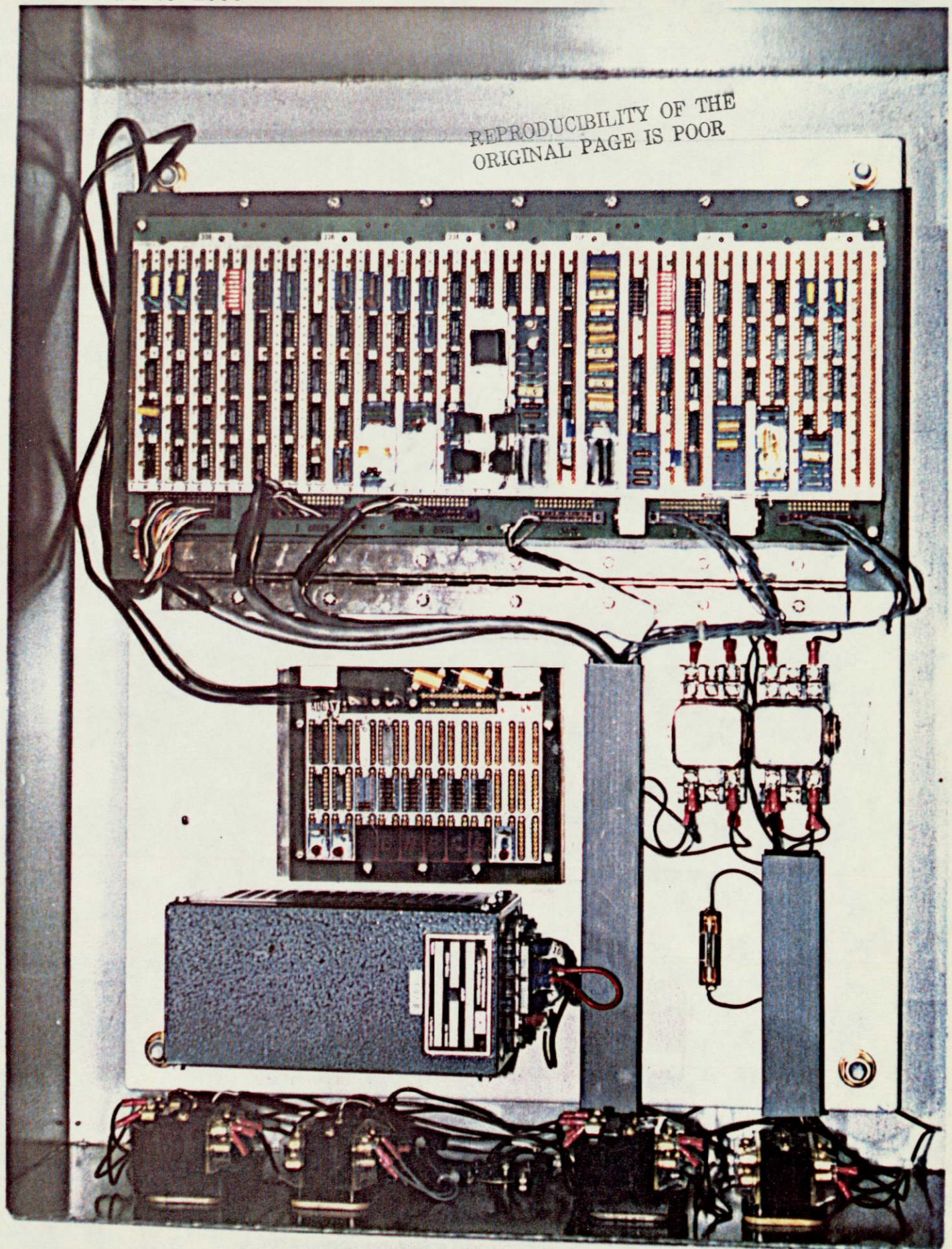


Figure 1.10.2 Electronic Circuitry

2.0 TEST RESULTS

2.1 General

The accuracy specification for the yaw measurement equipment required that the overall system be capable of calculating the true curve for a 150 foot coal face to within \pm 8 inches of its true position. This accuracy had to be maintained for longwall shear machine speeds from 0 to 40 feet per minute.

System accuracy was confirmed through the performance of 33 tests at the Bruceton facility. These tests included measurement across a straight track section, an inclined straight track section, a track section bowed 3 feet towards the coal face and a track section bowed 2 feet away from the coal face. All testing was performed on a conveyor track length of 120 feet. (See Figures 2.1.1 and 2.1.2).

2.2 Test Procedure

The initial test to confirm system performance was undertaken on a straight section of track with the shear machine operating at 10 feet per minute. The



Figure 2.1.1 Test Facility Storage & Computation Station



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Figure 2.1.2 Test Facility Data Plot

test results were positive and confirmed that the equipment could establish coal face position to less than the ± 8 inch specification. The straight track tests were rerun 5 additional times to confirm repeatability. Again the results were positive (Figure 2.3.1).

Testing was then performed on the straight track section with a machine speed of 30 feet per minute. Three tests confirmed that results were repeatable and similar to those obtained for the initial tests (Figure 2.3.2, Test 10,11,12).

The straight track was changed to simulate an uneven mine floor. This was accomplished by raising the gob rail 4 inches above the face rail midway along the track. Two tests were run at a machine speed of 10 feet per minute. The results were compared with the previous data and found to be in close agreement (Figure 2.3.2, Test 13,14).

The track was returned to a straight level condition and the contour measured again. As in the previous tests, the data compared favorably to that obtained during the first test. (Figure 2.3.2, Test 15).

The track was next bowed 3 feet towards the coal face. This bow was placed midway between the end points in an attempt to achieve large positive and negative deflection angles. Six tests were then performed over this surface and compared with the actual track curvature. The results were similar to those obtained previously (Figure 2.3.3 and 2.3.4).

The track was bowed 2 feet away from the coal face and four tests run. Again the results were similar to the initial test results. Error was always less than 8.2 inches absolute (Figure 2.3.5 and 2.3.6).

Finally the test track was returned to a straight line condition. Five tests were performed with variations made in the sampling distance. Three tests were performed using 50 samples over a 1 foot span (Figure 2.3.7). This was followed by taking 10 samples over a 2 inch span and 25 samples over a 6 inch span. The results were satisfactory for the 25 sample test but inferior for the 10 sample test. Also the short distance used for the 10

sample test made testing difficult since the discriminator performance became erratic and required manual assist to perform satisfactorily.

2.3 Test Summary

A sample printout for a number of the Bruceton tests are included in this report. This data was made available by NASA MSFC which conducted the tests and monitored their performance. The printouts and results are as follows:

Table 2.3 Test Results

Figure 2.3.1 Straight Track Contour

Figure 2.3.2 Straight Track Contour

Figure 2.3.3 Coal Face Bow Track Contour

Figure 2.3.4 Coal Face Bow Track Contour

Figure 2.3.5 Spill Rail Bow Track Contour

Figure 2.3.6 Spill Rail Bow Track Contour

Figure 2.3.7 Straight Track Contour

TEST	SPEED	ERROR (1)	ERROR (2)	REMARKS
4	10	REF		
5	12	-1.3		
6	11	-.7		
7	14	2.4		TWO BAD ANGLES
8	9	-1.6		
9	14	-1.9		
10	38	-2.9		
11	28	-2.3		
12	30	-2.3		
13	12	1.0		4 INCH HUMP
14	17	-4.6		4 INCH HUMP
15	20	-2.4		END OF STRAIGHT
16	19	-5.9	REF	START 3 FOOT FACE BOW
17	18	-2.0	4.4	ONE BAD BIAS
18	20	-6.2	-.8	
19	10	-5.5	.5	
21	18	-5.6	.4	
22	17	-4.7	1.8	END FACE BOW
23	17	-5.5	REF	START 2 FOOT GOB BOW
24	15	-8.3	-3.7	
25	15	-7.5	-2.9	
26	15	-6.5	-2.6	END GOB BOW
27	15	-4.3	REF	STRAIGHT AGAIN
28	14	-4.8	-.6	
29	16	-3.9	.7	
30	16	-4.2	.3	

- (1) TEST 4 IS ALWAYS REFERENCE
(2) REFERENCE IS UPDATED AS SHOWN

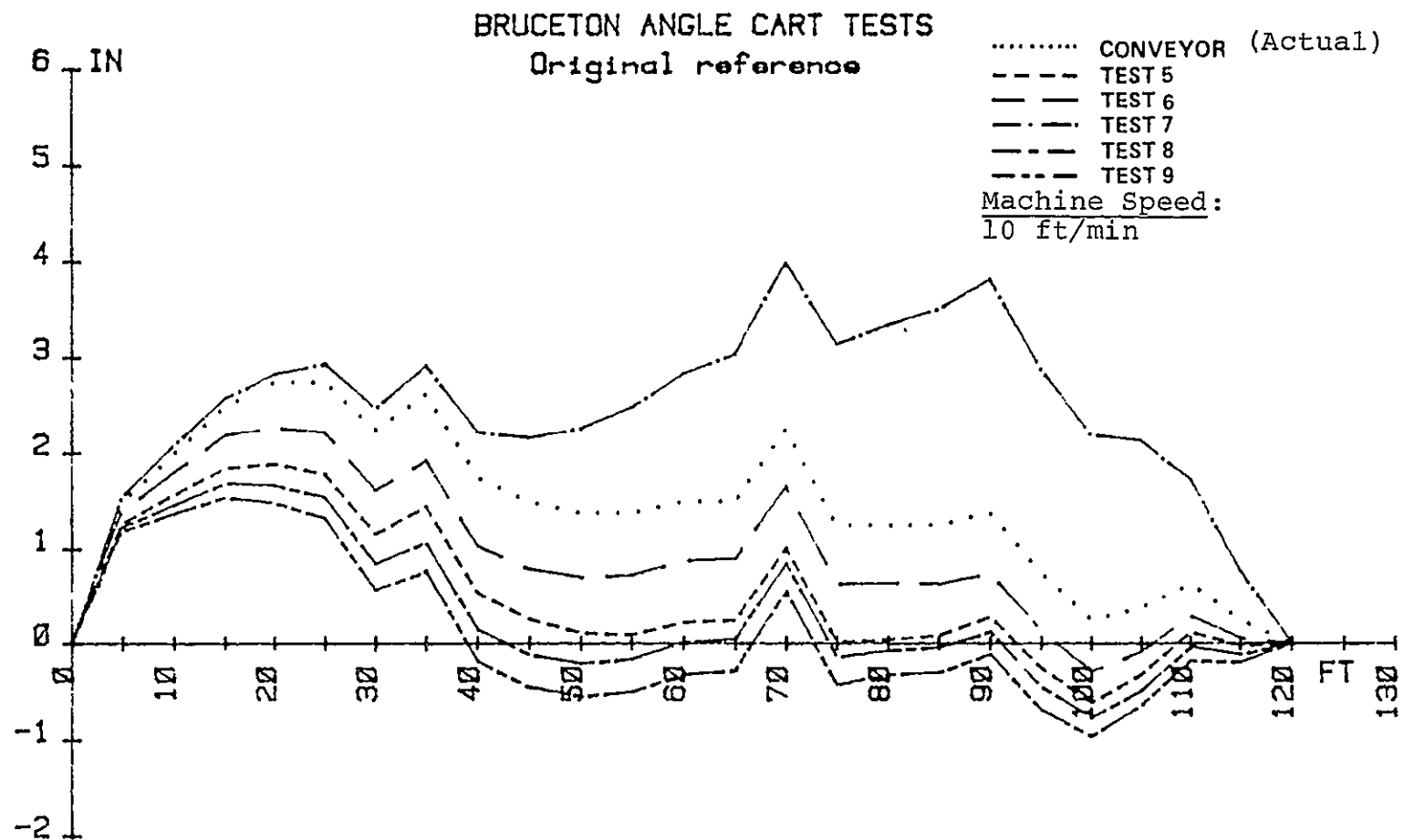


Figure 2.3.1 Straight Track Contour

EC1219

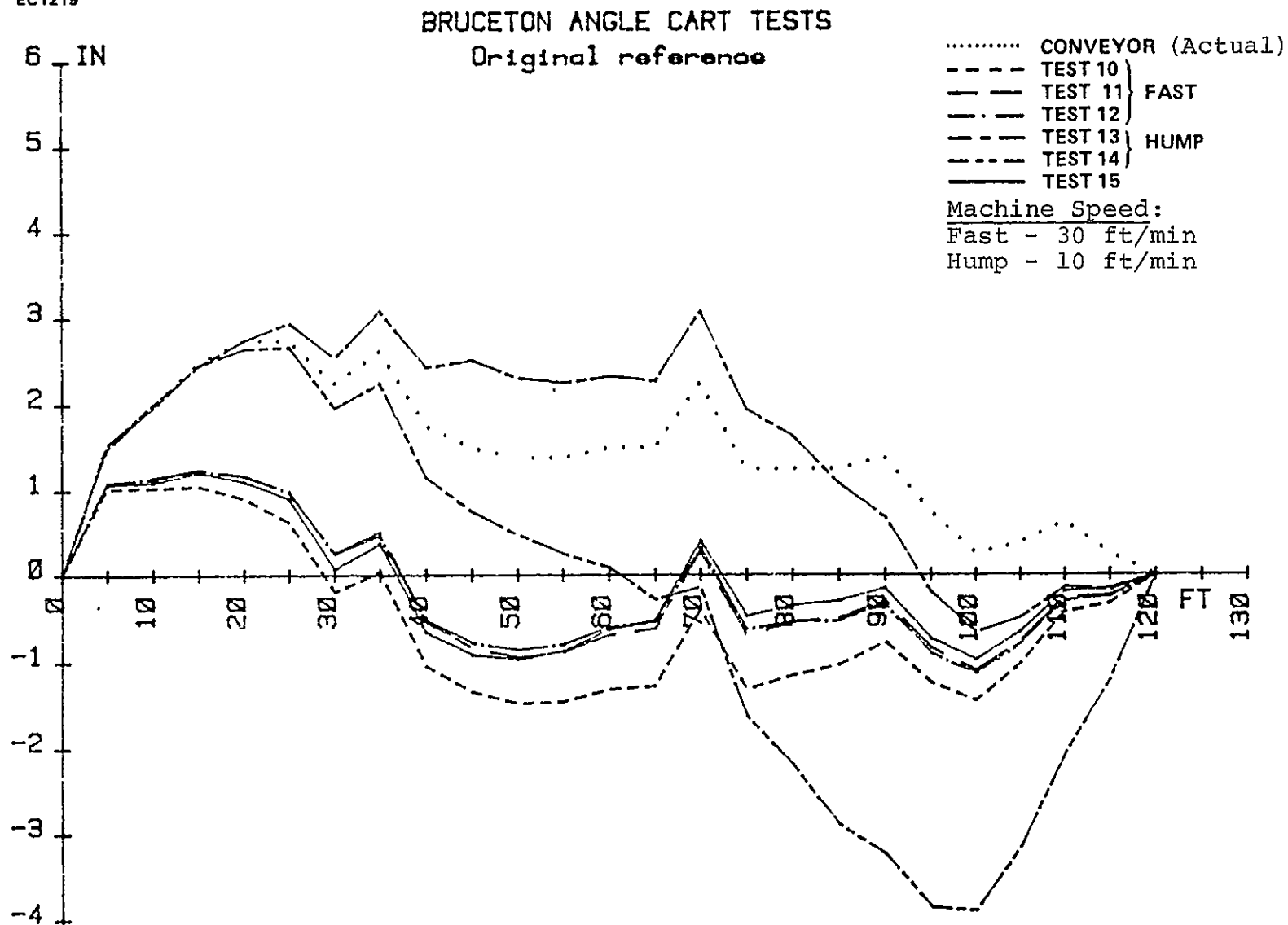


Figure 2.3.2 Straight Track Contour

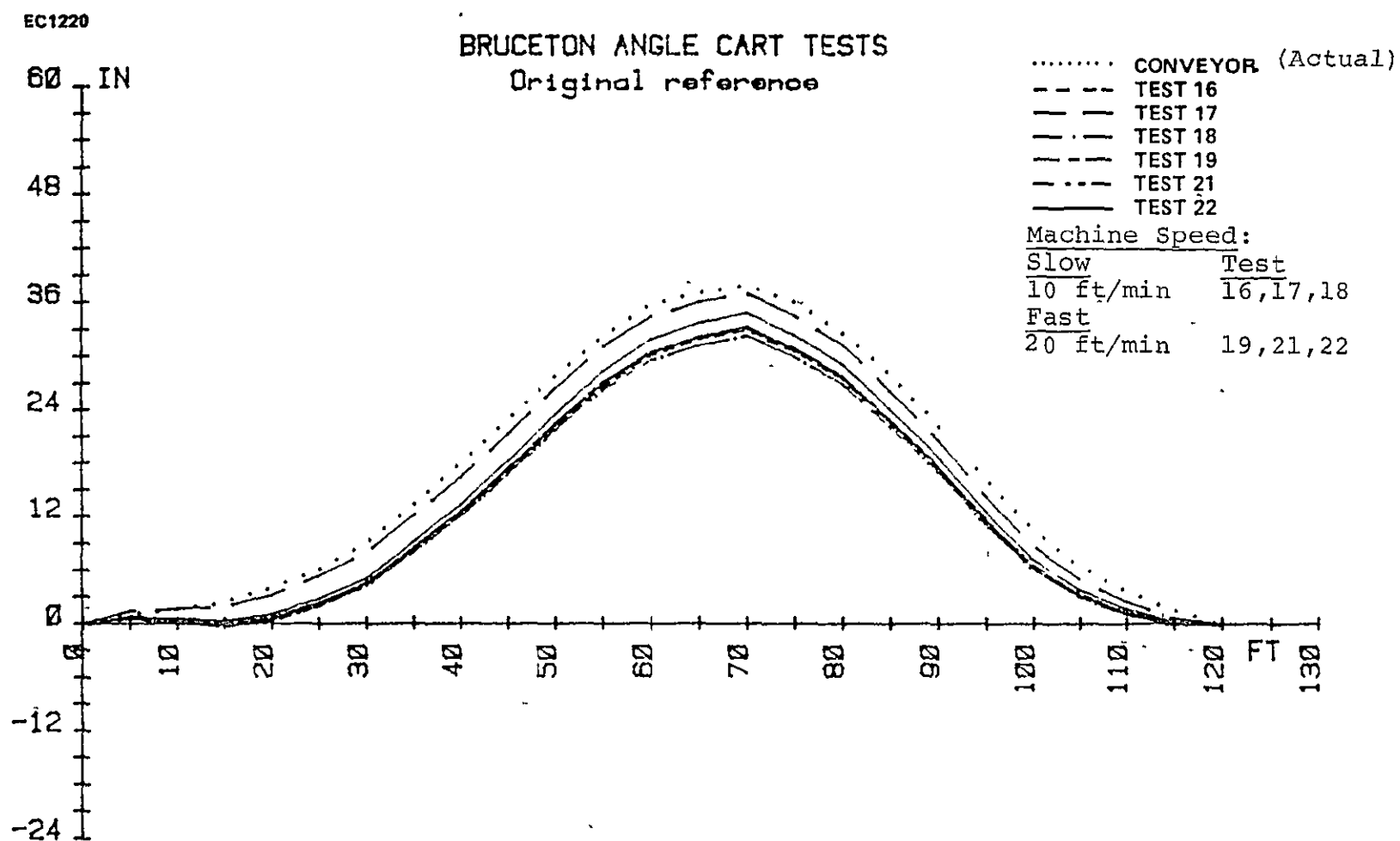


Figure 2.3.3 Coal Face Bow Track Contour

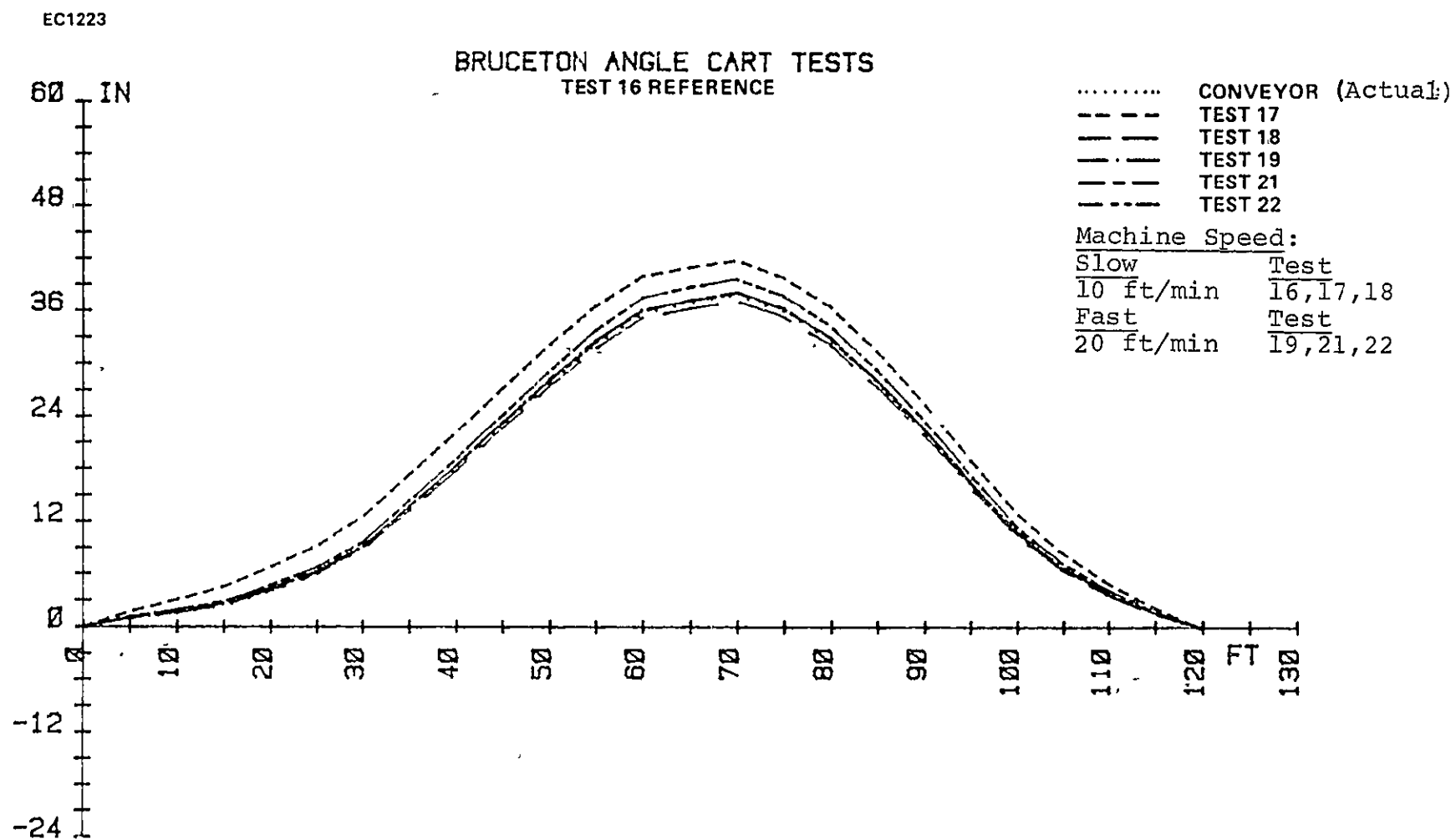


Figure 2.3.4 Coal Face Bow Track Contour

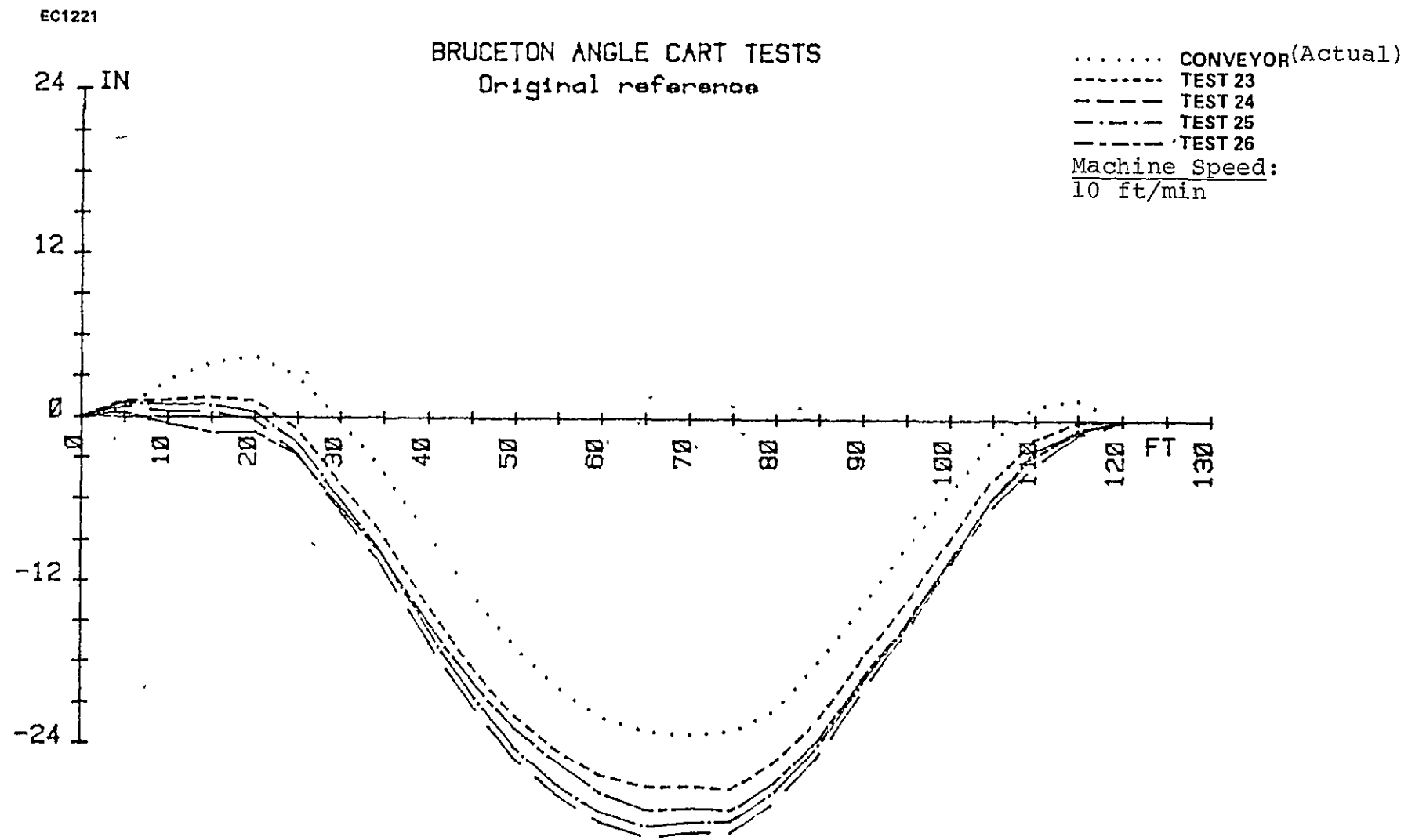
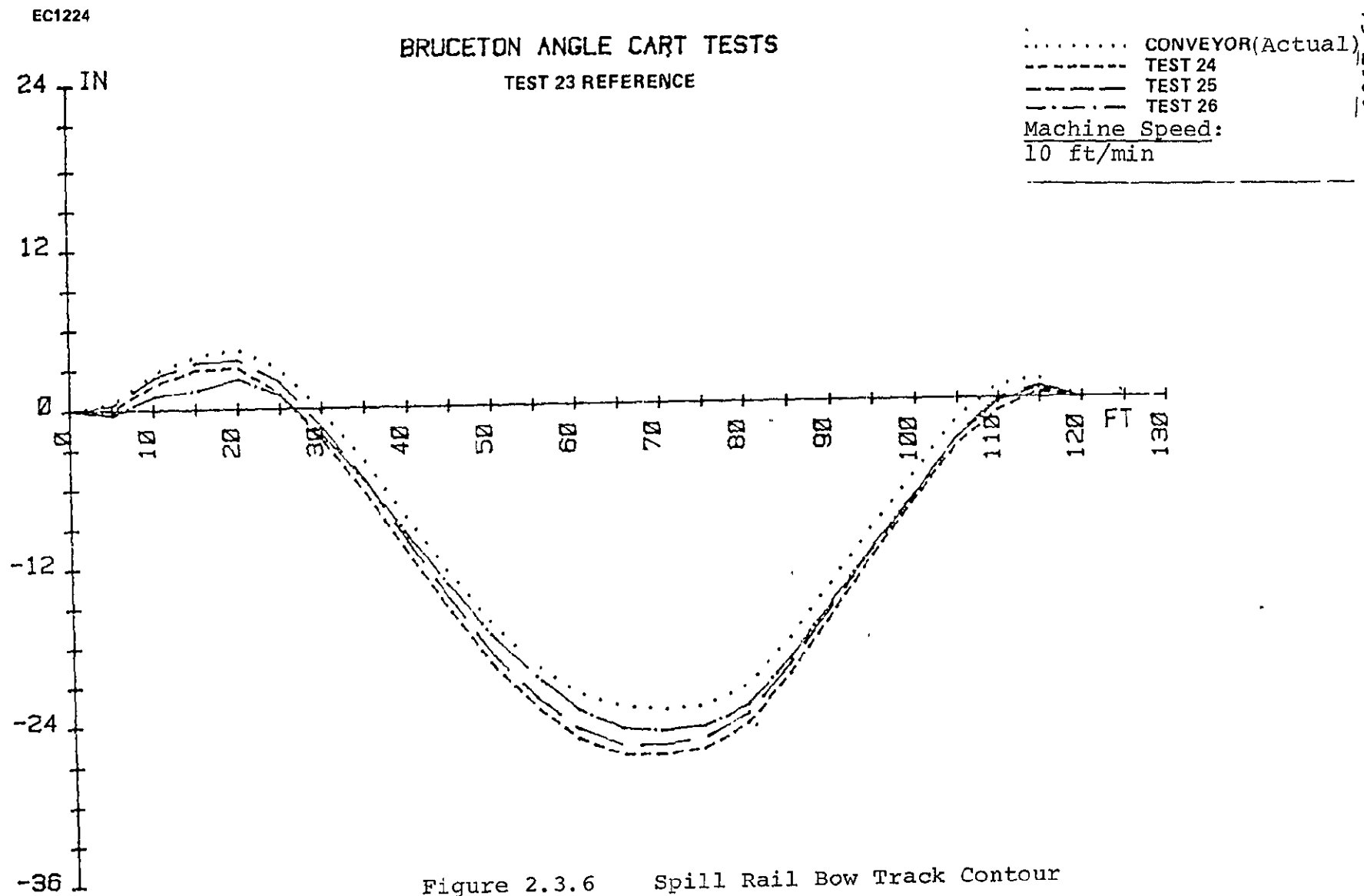


Figure 2.3.5 Spill Rail Bow Track Contour



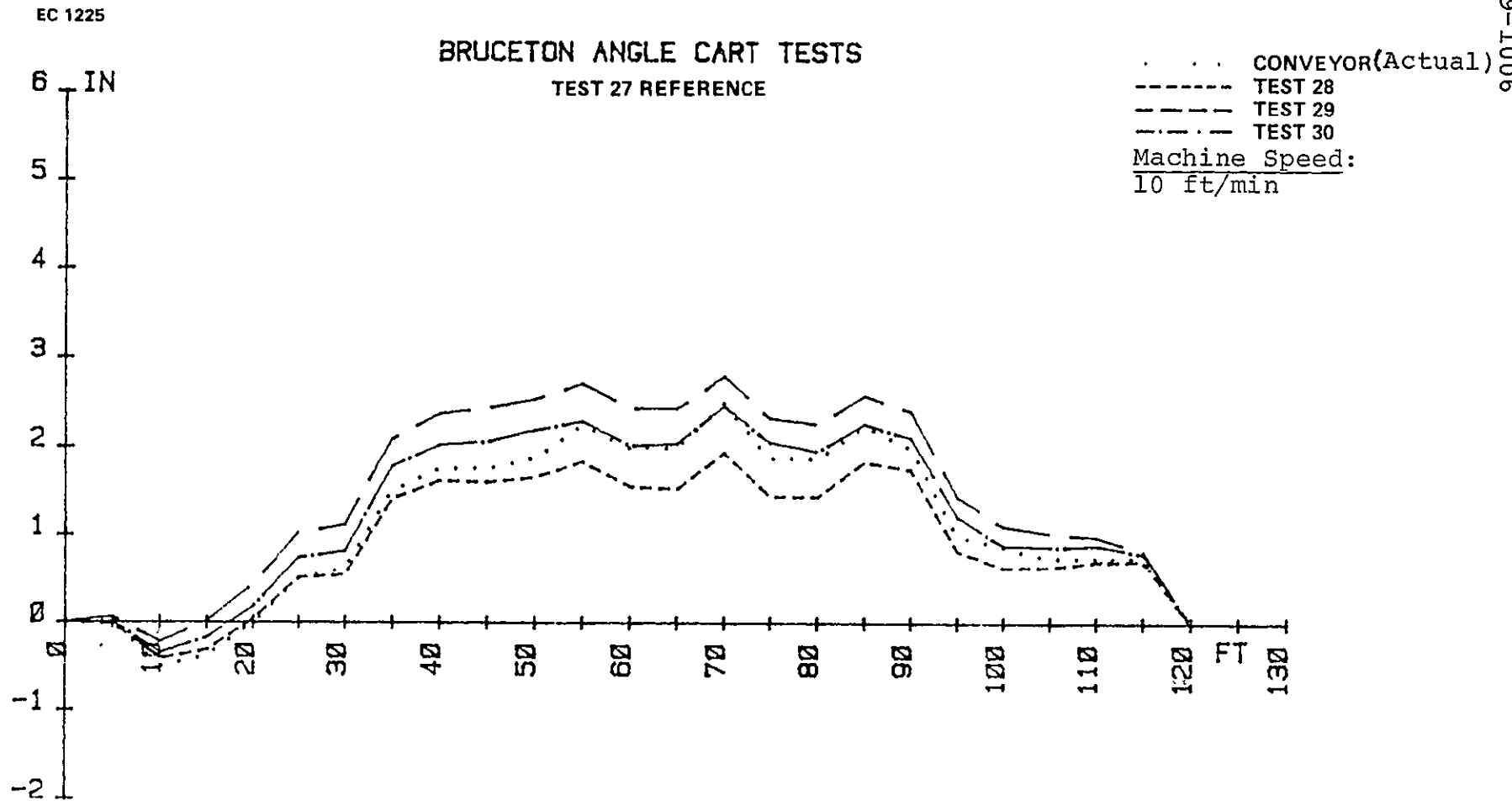


Figure 2.3.7 Straight Track Contour

3.0 CONCLUSION

The yaw measurement equipment verified that the contour for a longwall coal face can be determined by correlating the yaw movement of a mining machine with known end points of the coal face. The results obtained at Bruceton indicate that the target accuracy of ± 8 inches can be equalled and possibly bettered by at least a factor of two.

The environment at Bruceton presented no problems for the equipment. The electrical circuitry was housed in a NEMA type 4 enclosure that prevented exposure to direct water spray or coal dust. Shock and vibration were handled by the use of solid state electronics, elastic support membranes and shock isolation pads. The electrical transducers used were heavy duty models designed for severe service environments. Additionally, the transducers were placed in special housings designed to provide further protection from mechanical abuse.

The only shortcoming noted with the equipment was related to the angle transducer support structure. The need to measure yaw angle from the spill plate

surface dictated that this structure be cantilevered from the longwall shearer. Consequently this presented problems when the machine attempted to move around sharp bends. Lateral motion of the machine was amplified at the support structure and resulted in displacements that were beyond design limits. Thus manual assistance was required under certain test conditions to obtain valid data.

4.0 RECOMMENDATIONS

Several recommendations are made to establish the yaw measurement equipment as a viable method for measuring the coal face contour in an actual mine environment. These are:

1. The angle transducers should be placed within the shear machine. The best location is a point directly below the drive mechanism adjacent to the spill plate. This would provide a location with the least amount of lateral motion for the angle measuring transducers. It would also provide additional protection to the transducers from falling coal. This modification would require that

the longwall shear machine be modified to accept the transducer package and would require a cooperative effort with the machine manufacturer.

2. The GFE resolvers used to measure yaw angle should be replaced with less expensive devices. One technique is to use a gear train and a reasonably accurate resolver. Another is to use an 8:1 resolver whose accuracy is specified for a limited range of 10 degrees rather than for 360 degrees.
3. The electrical equipment should be made intrinsically safe. This is a necessary criteria for operation in an actual mine.
4. The storage and computational equipment that was discrete and separate from the angle measurement equipment should be replaced with microprocessing logic and the two consolidated into one package. This would permit the intrinsic safety requirement to be met for both units.